Quantitative Estimation of Vvariability in the Underwater Radiance Distribution (RadCam)

Marlon R. Lewis
Satlantic, Inc.
Richmond Terminal, Pier 9, 3481 North Marginal Road
Halifax, Nova Scotia, Canada B3K 5X8
phone: (902) 492-4780 fax: (902) 492-4781 email: marlon@satlantic.com

Scott D. McLean
Satlantic, Inc.
Richmond Terminal, Pier 9, 3481 North Marginal Road
Halifax, Nova Scotia, Canada B3K 5X8
phone: (902) 492-4780 fax: (902) 492-4781 email: marlon@satlantic.com

Award Number: N00014-07-C0139
http://www.satlantic.com

LONG-TERM GOALS

A significant source of uncertainty in the prediction of the apparent optical properties of the ocean is the geometrical distribution of the radiance field and its variation with respect to time and space; this uncertainty directly affects attempts to use measurements of reflectance and attenuation for the diagnosis of ocean constituents. Uncertainties in the time and depth dependent variations in the radiance distribution, and their sources of variation, propagate as well to the prediction of the performance of new imaging systems such as the “virtual periscope”. The problem starts at the sea surface, where the generally unknown sky radiance distribution, coupled with a roughened air-sea interface, plays a major role in the transmission of sun and sky radiance to below the surface. In the ocean interior, the volume scattering function, and the absorption coefficient alter the radiance distribution in both the forward and backward direction; in the perhaps usual situation of multiple scattering, the uncertainty in the radiance distribution becomes large. In optically shallow areas, non-Lambertian bottom reflectances add to the uncertainty.

Our long-term goal is to develop and deploy a relatively simple means for the measurement of the full radiance distribution, which could be routinely deployed by the optical oceanographic community. A further side benefit would be that many of the measurements currently made, such as planar and scalar irradiance, angle-dependent Q factor etc., could be made by various integration operations on the measured radiance field rather than with mechanical diffusers. The potential interferences of various deployment platforms (e.g. shading, reflectances by ships, buoys and towers) could be measured directly rather than inferred based on inaccurate assumptions about the underwater radiance distribution. A direct confirmation of the asymptotic radiance distribution can be made. Finally, high quality quantitative (and radiometrically calibrated) measurements of the radiance distribution, and their time and depth derivatives, can in principle (but not yet in practice) be used to estimate all the inherent optical properties (both absorption and volume scattering coefficient) and as well the nature of the air-sea interface.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2007	**Annual**	**00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE
Quantitative Estimation Of Vvariability In The Underwater Radiance Distribution (RadCam)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Satlantic, Inc.,Richmond Terminal, Pier 9, 3481 North Marginal Road,Halifax, Nova Scotia, Canada B3K 5X8, ,

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OBJECTIVES

The Radiance Camera or RadCam project is part of the Radiance in a Dynamic Ocean (RaDyO) program. The primary objective is to create a camera that can record the spatial radiance distribution at the ocean surface and at depth. The proposed instrument will be uniquely capable of resolving both the downwelling and upwelling radiance distribution and its variation with depth, time and wavelength ($L(z,t,\theta,\phi,\lambda)$); from these measurements, the apparent optical properties E_D, E_U, E_o, E_{ou} and E_{od} are computed by integration. The distribution functions (e.g. the average cosines) are computed directly, as are the various diffuse attenuation coefficients and reflectances. The fully-specified radiance field therefore provides all the pertinent information to derive not only the apparent optical properties, but the inherent optical properties: the absorption coefficient and, in principle by inversion, the volume scattering function. An instrument capable of this measurement to the necessary accuracy, resolution, and noise characteristics could, again in principle, replace all or most of the optical instruments currently deployed today..

APPROACH

While radiance cameras have been built before, they have not been able to image the sun at the surface due to the very high scene dynamic range. RadCam will take advantage of recent developments in high-dynamic range (HDR) CMOS imaging arrays. These arrays were developed for science, surveillance, and automotive applications. Traditional CCD arrays are linear, limiting the dynamic range that can be achieved. These HDR CMOS arrays use a number of different methods to produce a nonlinear response function, giving scene dynamic ranges of up to 120 dB or 6 decades.

WORK COMPLETED

In the first year of this project we considered several possible cameras and imaging arrays. We tested two candidate cameras/arrays and selected one for RadCam. Measurements have shown that it can achieve a scene dynamic range of 6 decades, and an impressive system dynamic range of nearly 10 decades.

Three instruments are being designed as part of this project. The first is a reference camera that will be mounted on deck. The second is a logging-type instrument that can be mounted on a Bluefin AUV or an ROV. The third is a profiler that sends data to the surface for real-time processing. The first two cameras are upward looking only (i.e. they record downwelling radiance) while the profiler has both an upwelling and downwelling camera. This allows it to measure radiance over the entire sphere around the instrument.

At this time, only the first two cameras are being built, though the design considers the profiler.

RESULTS

Optics

A fisheye lens with a specified 185 degree field of view was selected for use in the camera. A custom optical system, shown in Figure 1, was designed to reduce the image size produced by the fisheye to fit

totally within the CMOS array. The system also contains a bandpass filter centered at 555 nm with a bandwidth of 20 nm.

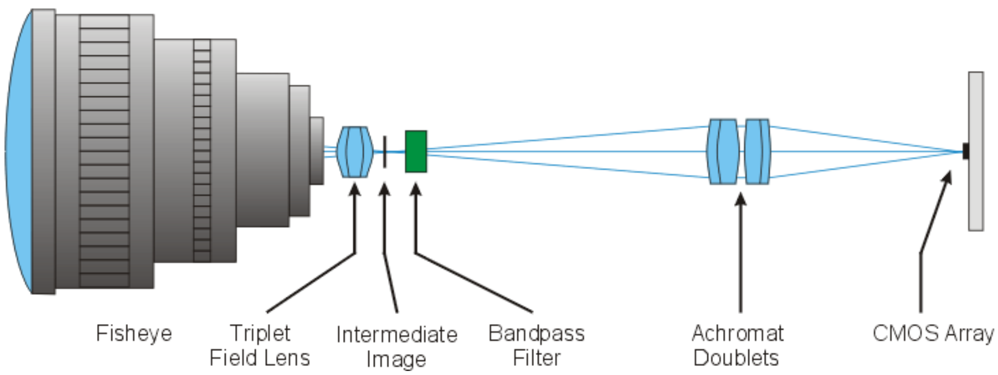

Figure 1: Custom optical system used to reduce image size and spectrally filter the image. It includes a fisheye lens, field lens, filter, a pair of achromat doublets and the CMOS array.

The geometric mapping of the optical system is shown in Figure 2. Most fisheye lenses use an equidistant projection, where the field angle maps linearly to a radial position in the image. The measurements show a field angle of 190 degrees mapped to an image 466 pixels in diameter. This corresponds to an angular resolution of about 0.4 degrees/pixel, better than the 1 degree/pixel specified at the outset of the project.

The rolloff of the optical system is shown in Figure 3. The measurements show a drop in throughput to 92% at a field angle of 95 degrees. This drop is almost entirely due to the fisheye lens. Thus the custom optical system exhibits excellent performance.

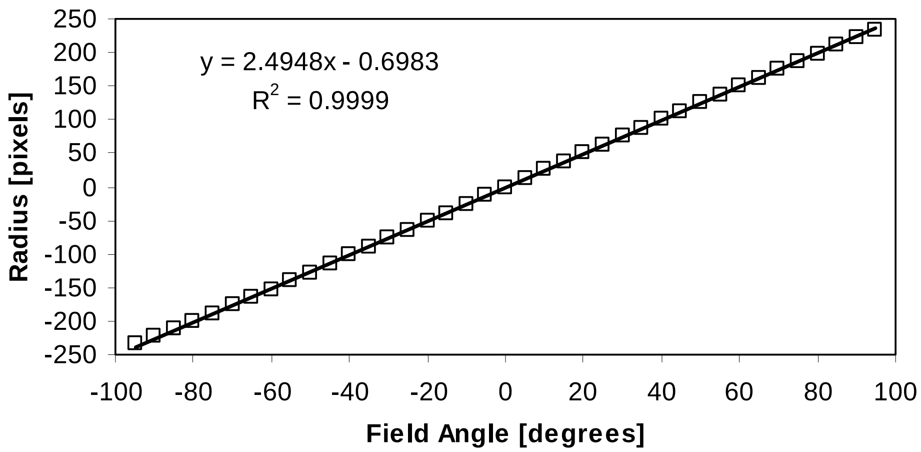

Figure 2: Graph of the geometric projection of the optical system (image radial position versus field angle) showing that the relationship is very linear.

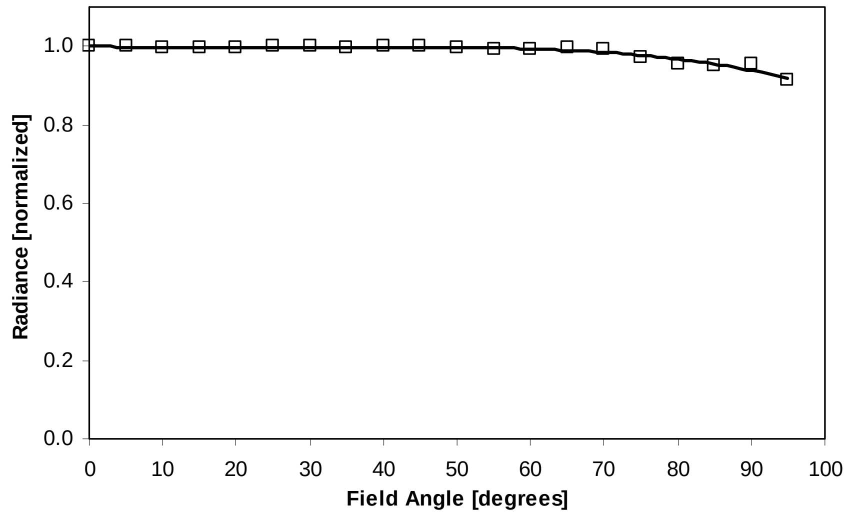

Figure 3: Graph showing the rolloff of the optical system. The rolloff is negligible out to about 60 degrees field angle and drops to about 92% at 95 degrees.

Figure 4 and Figure 5 show the assembled optical system, including the camera electronics.

Figure 4: Side view of the camera assembly showing the fisheye lens, custom optical system, a translator for accurately positioning the image on the array, and camera electronics. The whole assembly is 16 cm long.

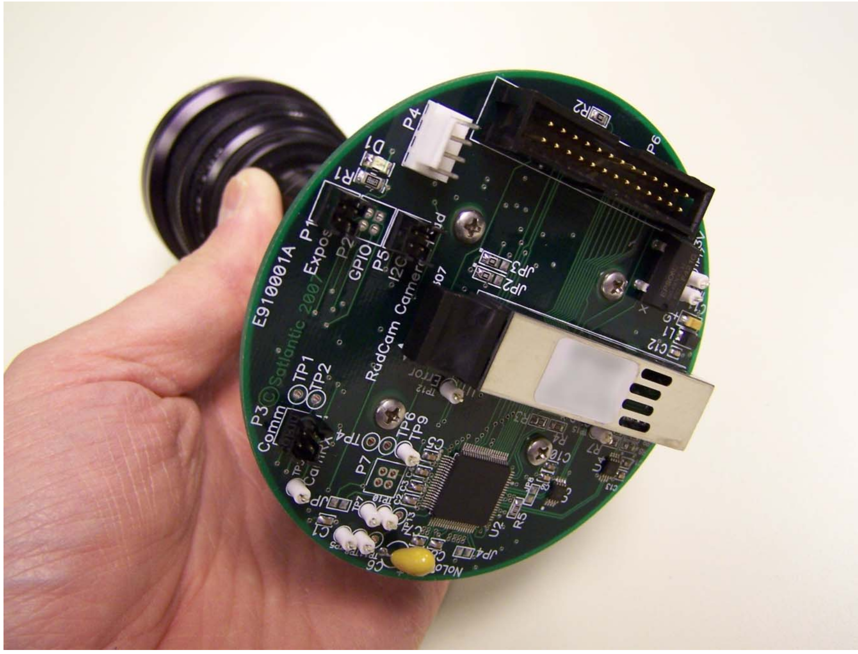

Figure 5: Picture of the backside view of the custom camera circuit board. The metallic box is the fiber transceiver.

Electronics

Custom electronics were required to serialize the video stream from the camera (Profiler and ROV/AUV) and transmit it over a fiber optic cable to a computer on-deck for real time processing. The serialized data rate is approximately 500 Mb/s. At the surface the data is deserialized and sent to a framegrabber. The framegrabber assembles the images and transfers them to memory for processing. The boards have been designed, built, and tested, with the exception of the connection to the framegrabber. The custom camera board was designed such that it can be used in any of the instruments.

The instruments were designed to handle data from ancillary sensors including tilt/heading and pressure. The profiler will include a full suite of instruments including integrating radiometers, attenuation and backscatter meters and others. The data from these instruments is interleaved with the video data stream.

The ROV/AUV camera has no connection to a deck unit and logs data onboard. A PC104-style computer captures and stores the video and ancillary sensor data. On retrieval of the instrument, the data is offloaded using a high-speed ethernet connection. The only real-time processing performed on-board is determining which exposure to use.

Software

Much of the instrument control software has already been written for the cameras. It is written in Java with interfaces to native C code for specific third-party hardware. Java simplifies the development of a

user interface including displaying live video and camera control. It will interface with existing Satlantic code to display and log ancillary sensor data.

Images will be processed in real time, though the maximum frame rate will depend on the processing power of the computer and still needs to be determined. Processing includes applying calibration coefficients to each pixel, compensating for tilt/heading, and calculating apparent and inherent optical properties (see Figure 6). The software must also determine when a change in exposure is required. This last task is not trivial and has not yet been implemented.

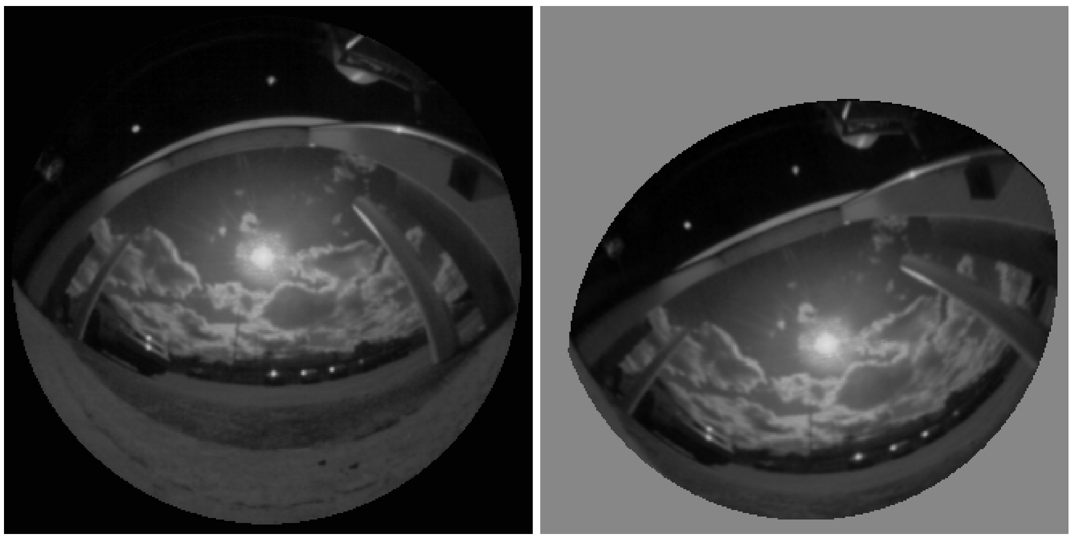

Figure 6: Test image (left) and output (right) of the tilt/heading compensation algorithm. User supplied tilt and heading information were used instead of real sensor data, for testing purposes. The compensated image shows a crescent shaped area that corresponds to a region outside the fisheye field of view.

Calibration

The calibration of the CMOS array is one of the most challenging parts of the RadCam project. Unlike CCDs which have a quite uniform response over the array, every pixel in a CMOS device has a slightly different response (grayscale versus radiance). This is because each pixel in the CMOS array contains its own electronics. Thus every pixel in the array must be individually calibrated.

Particular challenges for calibrating RadCam are the very large dynamic range and the very high peak radiance ($7*10^6$ uW/cm^2/nm/sr). Two methods of measuring the response curves were used. The first is a standard method that uses a NIST traceable FEL lamp, a rail, and neutral density filters. Images are captured from the array at several distances from the lamp. The limited power and point source nature of the FEL lamp do not allow it to be used for the highest end of the response curve. An arc lamp was tested but a beam of sufficient spatial uniformity could not be produced. We now use a HeNe laser as the source and scan the array behind it. While the beam from a HeNe is Gaussian, it was found to be sufficiently uniform over a small spot (few tens of microns in diameter) that it could be used for calibration. During development of the calibration procedure a nonlinearity in the array

was observed. At high radiances the grayscale response of the array can saturate and then decrease – an effect the manufacturer describes as eclipsing. On-chip circuitry is used to combat the problem and works well when small numbers of pixels are brightly illuminated. When large numbers of pixels are brightly illuminated the problem is still observed. Only solar and nearby pixels should reach these radiance levels, so the final images should be accurate, though some verification will be performed.

Software was written to semi-automate data collection during calibration. It takes care of scanning the array behind the HeNe, isolating relevant data, and averaging frames together to reduce temporal noise. Software was also written to process the large calibration data sets. The program takes care of fitting together data runs, sectioning the nonlinear response curves, and fitting polynomials and hyperbolics to the sections. A final calibration coefficient file is about 30 MB per exposure setting.

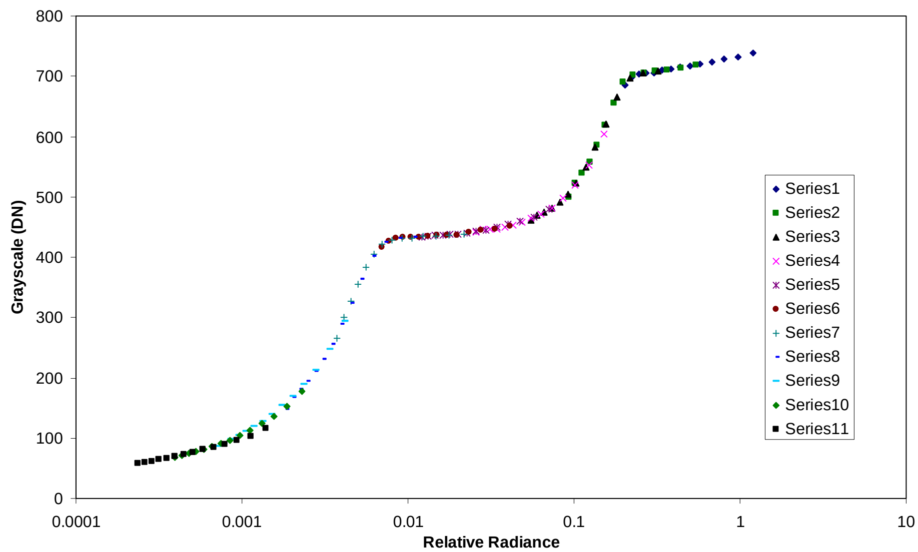

Figure 7: Calibration data showing runs, fitted together to produce an overall response curve. At the left end, there are some fitting problems believed to be due to stray light during data capture. Data for the high-radiance end of this exposure is not shown.

While the system will operate over nearly 10 decades of dynamic range, only about 6 decades can be captured using any particular exposure. Therefore, a search was performed to determine which exposure settings would be suitable. We have decided on three exposures that cover a dynamic range of more than 9 decades. The roughly measured curves are shown in Figure 6.

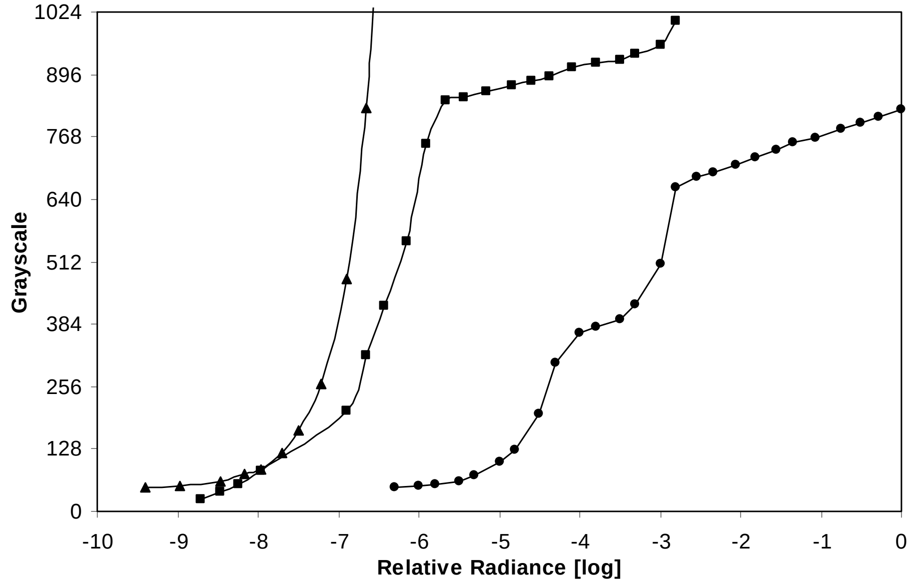

Figure 8: Graph showing roughly-measured response curves (grayscale versus relative radiance) for three different exposures that will be used in RadCam. The first exposure, suitable for use at the surface, has about 6 decades dynamic range. The second exposure extends from about –3 decades to nearly –9 decades. The third exposure extends from about –6.5 decades to about –9.5 decades.

Mechanical

Figure 9 shows the basic layout of two of the RadCam instruments; the ROV/AUV camera and the Reference camera. The ROV/AUV camera is wider to accommodate a PC104 computer, while conforming to the space limitations of a Bluefin AUV instrument bay. There are some additional components that will be in the instrument, including a pressure sensor, that are not shown. The Reference camera is shown with a dome but will be operated without the dome eliminate reflections and glare.

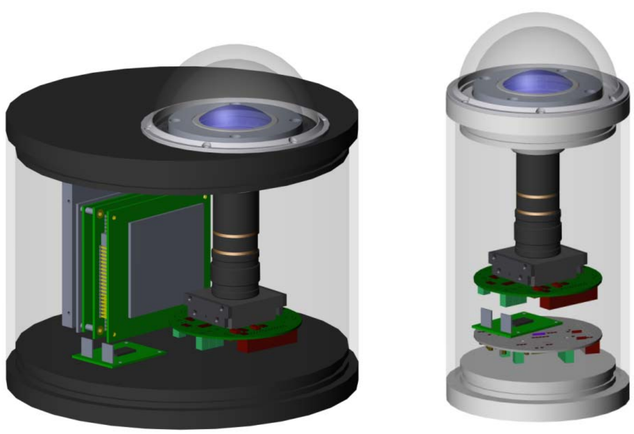

Figure 9: Mechanical layout of the ROV/AUV camera (left) and the Reference camera (right).

IMPACT/APPLICATIONS

The camera may have applications for various sorts of surveillance. The derivation of optical properties from measurement of the full radiance distribution may have practical applications.

RELATED PROJECTS

This project is embedded within the Radiance in a Dynamic Ocean (RaDyO) program, and hence is related to all projects contained therein.

HONORS/AWARDS/PRIZES

Lewis, M.R.: Awarded Killam Professor of Oceanography, Dalhousie University, Killam Foundation.